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An Assessment of Health and Disease in the Prehistoric Inhabitants of the Mariana Islands

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ABSTRACT Using a variety of skeletal and dental stress indicators, an assessment of the health and disease of the indigenous inhabitants of the Mariana Islands, the Chamorro, is made. The major hypothesis to be tested is that the Chamorro were relatively healthy and that deviations from the expected, as well as inter-island variation, may reflect environmental, ecological, and cultural differences. The major skeletal series surveyed include sites on Guam (N = 247 individuals), Rota (N = 14), Tinian (N = 20), and Saipan (N = 102). The majority of the specimens are from the transitional pre-Latte (AD 1–1000) and Latte (AD 1000–1521) periods. These data derive primarily from unpublished osteological reports.

The indicators of health and disease surveyed include mortality and paleodemographic data, stature, dental paleopathology, cribra orbitalia, limb bone fractures, degenerative osteoarthritis, and infectious disease (including treponemal infection). Where appropriate, tests of significance are calculated to determine the presence of any patterning in the differences observed within and between the skeletal series. Information recorded in prehistoric Hawaiians provides a standard for external comparisons.

Several of the larger skeletal series surveyed have paleodemographic features that are consistent with long-term cemetery populations. Females and subadults are typically underrepresented. Most subadult deaths occur in the 2–5 year age interval. Life expectancy at birth ranges from 26.4 to 33.7 years. A healthy fertility rate is indicated for these series. The prehistoric inhabitants of the Mariana Islands were relatively tall, exceeding living Chamorros measured in the early part of the present century. The greater prevalence of developmental defects in the enamel suggests that the Chamorro were exposed to more stress than prehistoric Hawaiians. The low frequency of cribra orbitalia further indicates iron deficiency anemia was not a problem. There are generally low frequencies of dental pathology in the remains from the Mariana Islands. Betel-nut staining is relatively common in all series which may help to explain the relatively low prevalence of dental pathology.

Healed limb bone fractures are rare in these skeletal series; the frequency and patterns of fractures suggest accidental injury as the main cause. Greater physical demands involving the lower back region are indicated by a high

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frequency of spondylolysis, or stress fracture in the lumbar vertebrae in the Chamorro. Likewise, advanced degenerative bone changes, while of low occurrence, are significantly greater in the Chamorro than Hawaiians. The prevalence of skeletal and dental indicators of stress was generally higher in the smaller islands of the Marianas chain (e.g., Rota), islands with fewer resources to buffer environmental catastrophe. Bony changes suggestive of treponemal (probably yaws) disease are common in most of these Marianas Islands skeletal series. Am J Phys Anthropol 104:315–342, 1997. © 1997 Wiley-Liss, Inc.

Human skeletal remains often comprise a very conspicuous part of the archaeological record and provide anthropologists with a unique opportunity for studying past human conditions. Disease experience, nutritional patterns, physical activity, length of life, and cultural behaviors, among others, may leave a lasting imprint on bones and teeth. Skeletal indicators of general stress include paleodemography data and the prevalence of dental enamel hypoplasias. Indicators of more specific physiological stressors include evidence of infectious disease, trauma, osteoarthritis, dental pathology, and porotic hyperostosis. In recent years, the measurement and interpretation of stress indicators in the human skeleton and dentition have assumed a prominent position in skeletal biological research for assessing biocultural adaptation in prehistoric communities (see e.g., Goodman et al., 1984; Martin et al., 1985; Rose et al., 1985; Saunders and Katzenberg, 1992; Larsen and Milner, 1994; Grauer, 1995). While abundant published data for assessing health and disease in humans exist, few researchers have examined biocultural adaptation to island ecosystems.

The major objective of this paper is to examine selected skeletal and dental indicators of stress in the prehistoric inhabitants of one Pacific island ecosystem: the Chamorro of the Mariana Islands. The primary data surveyed are from unpublished osteological reports written by Pietrusewsky and coworkers which have resulted from archaeological mitigation projects undertaken in the region in recent years. Examination of skeletal series from more than one island in the chain will allow comparisons which may reflect local differences in environment (e.g. differential susceptibility to typhoons), culture (including diet), or other factors. Lastly, to further assist in the interpretation of the Mariana Island data, limited comparison will be made with a fairly well documented sample from Hawai'i. The present study is one of the first syntheses for the Mariana Islands, which is based on systematically recorded data that use a single common standard.

THE MARIANA ISLANDS AND THE CHAMORRO

The Mariana Islands, located approximately 2,400 km east of the Philippine Islands in the western Pacific, consist of two broad arcs of islands (Fig. 1). All of these islands are volcanic in origin, but those in the south (including Guam, Rota, Tinian, and Saipan), the main focus of this synthesis, are further overlaid with raised platforms of coral (Thomas, 1963). By convention, these four islands are considered "high islands," the maximum elevations ranging from 400 m to 500 m (Hunter-Anderson and Butler, 1995), but are small in size (33 sq mi–207 sq mi), resulting in rather steep slopes on the hillsides. Evident from the map is the close proximity of Saipan and Tinian to each other (approximately 5 km), and the rather isolated position of Rota. Rainfall is not exceptionally high in the southern Marianas and it is unevenly distributed throughout the year (Alkire, 1977). For some of the Mariana Islands, e.g., Rota, there is little surface water and serious water shortages can occur (Butler, 1988). In addition to being susceptible to droughts, severe tropical storms or typhoons cause periodic devastation of reef systems and terrestrial vegetation, contamination of fresh water sources with sea water, and damage to other resources on these islands. The prehistoric diet of the Mariana Islanders was rich

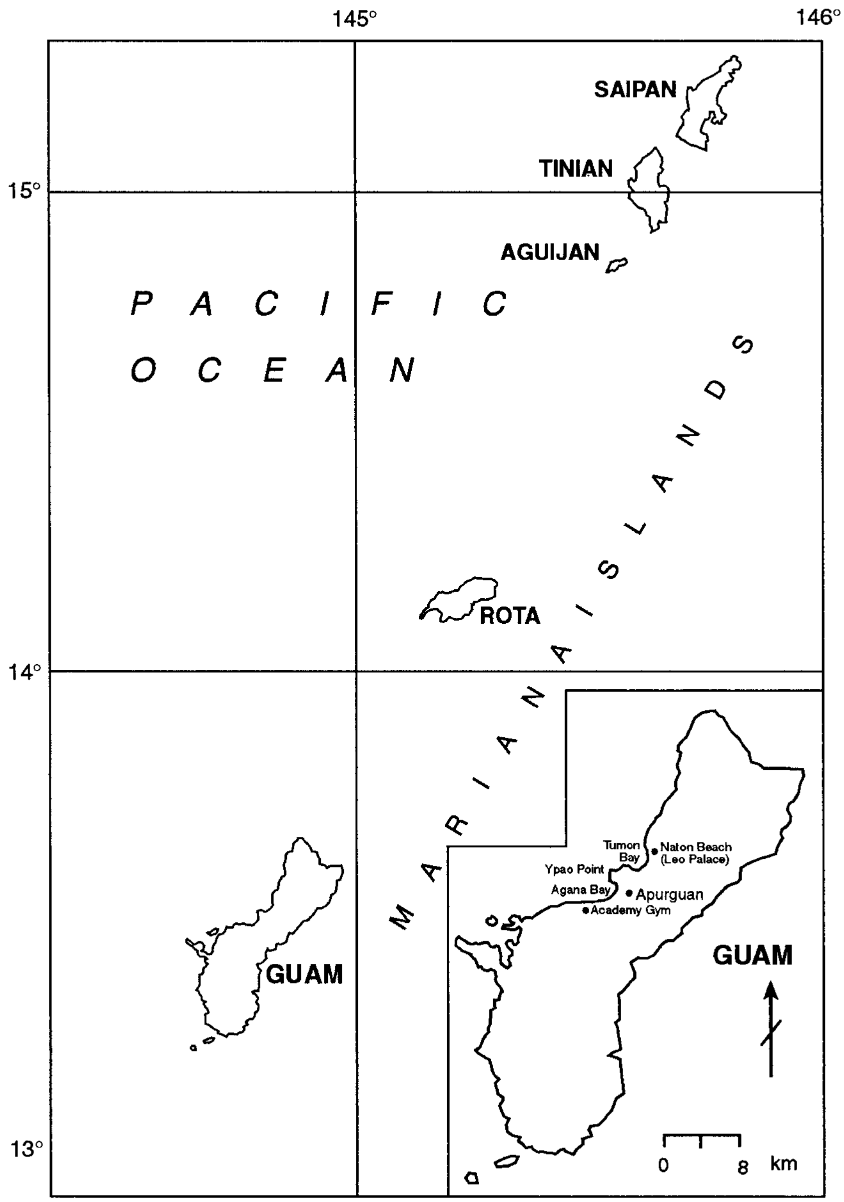

Fig. 1. Map showing the approximate locations of the human skeletal material from the Mariana Islands examined in the present survey.

in marine resources found in the reefs, reef flats, and deep water environments (Alkire, 1977; Butler, 1988). Birds, crabs, and bats may have provided additional protein but the islands had very limited terrestrial fauna. The plants cultivated are typical of the tropical island environment, including coconut, banana, breadfruit, taro, yam, and possibly rice, foods rich in carbohydrates. The mineral content of drinking water and food is another matter of concern in island ecosystems.

Chamorro culture is traditionally divided into three periods: pre-Latte, Transitional, and Latte phases. The term Latte is applied to a form of paired stone pillar architecture

which was used to support houses, meeting halls and religious structures (Davis, 1990; Graves, 1986; and Hanson, this issue). On the larger islands, principally Guam, during the pre-Latte period (1800 BC–AD 1000) population size was small, consisting of coastal villages which relied on fishing, shellfish and agricultural subsistence. The transitional pre-Latte period (AD 1–1000) saw an increase in population growth and settlement expansion with a thicker pottery and reef fishing. The Latte period (AD 1000–1521) is characterized by the presence of the latte structures, large thick pottery, a shift from bivalve to gastropod shellfish, deep water fishing and larger villages. The chronological sequence used here is based on work by Moore (1988).

Latte structures are nearly always associated with burials, typically interred within the perimeter defined by the latte postholes and perpendicular to the length of the structure. Burials recovered outside the defined latte tend to be more variable in position and orientation (Davis, 1990; Graves, 1991).

The technology of the prehistoric Chamorro included, amongst other things, digging sticks and stone-hafted implements (Alkire, 1977). The men engaged in most of the work associated with planting and harvesting, and activities that required heavy physical labor such as house and canoe building, and latte construction. Women were responsible for the collection of marine resources, preparing food, and making baskets, mats, and pottery (Alkire, 1977).

The earliest known Western contact with the Chamorros was made by the Spanish (Magellan) in 1521. Subsequent brief contacts culminated in the establishment of an active trading center on Guam by 1570. The Spanish remained in power until 1899, exacting a tremendous toll on the inhabitants of the Marianas in the form of disease, warfare, and resettlement.

RESEARCH QUESTIONS

A study of dental health and disease in one other prehistoric Pacific Island group, Hawai'i (Pietrusewsky and Douglas, 1994), has demonstrated low frequencies of occurrence for many of the indicators examined in the present study. Given the broad similarities between Hawai'i and Guam, including adequate diets, absence of introduced infectious diseases, and other similarities in island climate and environment, it is predicted that estimators of physiological stress should be roughly comparable, although treponemal (yaws) infection was present in the latter group. Further, given the smaller sizes of the Mariana Islands and hence their greater susceptibility to natural catastrophes, such as typhoons and ensuing food shortages, slightly higher frequencies of these indicators of stress in the Chamorro are predicted. Based on the relative size of the islands within the Marianas, it is further expected that the highest frequencies of these indicators of stress should be found in skeletal samples from Rota, followed by decreasing frequencies in series from Tinian, Saipan, and finally, Guam. Other differences in the expected frequencies of stress indicators may be attributed to cultural and occupational differences in these skeletal series.

CHAMORRO SKELETAL SAMPLES

Although the relative paucity of information on the prehistory of portions of Micronesia is rapidly being amended (Hunter-Anderson, 1990; Hunter-Anderson and Butler, 1995), the availability of adequate samples of human skeletal remains is still a major obstacle to addressing issues in Micronesian skeletal biology and bioarchaeology. Among the earliest published works that utilize human skeletal remains from the Mariana Islands are those by Leigh (1929), Wood-Jones (1931), and Stewart and Spoehr (1952). These latter skeletal remains were excavated in the 1920s by H. Hornbostel and T.C. Thompson mostly on Guam for the Bishop Museum (Honolulu), where they are currently stored. More recent studies of this same skeletal material have also appeared (e.g., Hanihara, 1986; Suzuki, 1986; Koizumi, 1986; Brace et al., 1990; Dodo, 1986; Turner, 1990; Pietrusewsky, 1990a, 1990b, 1994a; Howells, 1989, 1990).

Outside of the Bishop Museum collection, only a few preliminary reports on skeletal remains from the Marianas have appeared in the literature (e.g., Underwood, 1977).

TABLE 1. Skeletal series from the Mariana Islands

Island	Project/site	MNI[1]	Site dates	Reference
Guam	Matapang Park, Tumon Bay	20	AD 770–1025[2]	Pietrusewsky (1986a), Bath (1986)
Guam	Fujita Drainfield, Tumon Bay	28	AD 590–900	Pietrusewsky (1986a), Bath (1986)
Guam	Right-of-Way, Tumon Bay	16	AD 1480–1665	Pietrusewsky (1986a), Bath (1986)
Guam	Apurguan, Tamuning District, Agana	152	AD 1000–1521	Pietrusewsky et al. (1992), McNeill (1995)
Guam	Leo Palace Hotel Site, Tumon Bay	27	AD 1000–1400	Douglas and Ikehara (1992), Davis et al. (1992)
Guam	Academy Gym, Agana	4	pre-1521	Ikehara and Douglas (1995), Welch (1991)
Rota	Songsong Village	12	AD 1050–1530	Pietrusewsky (1988), McManamon (1989)
Rota	SNM Hotel	2	Latte Period 700–250 BP	Pietrusewsky (1994b), Craib (1994)
Tinian	Latte House Site	6	Latte Period	Pietrusewsky and Batista (1980), Russell (1978)
Tinian	Unai Chulu	14	pre-1521	Pietrusewsky (1986b), Ward and Pickering (1985)
Saipan	Marianas High School	5	no dates	Pietrusewsky and Batista (1980), Russell (1978)
Saipan	Grotto Site	2	AD 720–210 ± 100	Pietrusewsky and Batista (1980), Russell (1978)
Saipan	San Antonio	33	AD 1230–1360 ± 100	Pietrusewsky and Batista (1980), Russell (1978)
Saipan	Hafa Dai Beach	20	pre-1521	Pietrusewsky (1986b), Ward and Pickering (1985)
Saipan	Tanapag	7	pre-1521	Pietrusewsky (1986b), Ward and Pickering (1985)
Saipan	Oleai	35[3]	pre-1521	Pietrusewsky and Douglas (1989), Graves (1995)

[1] MNI = minimum number of individuals.
[2] The majority of the Matapang burials are from the Latte Period (AD 770–1025), but three are dated to 1690 BC–1140 BC.
[3] One individual was inadvertently excluded from the age/sex table in Pietrusewsky and Douglas (1989).

The situation for the Marianas, particularly for Guam, is much better than for the rest of Micronesia, corresponding to the intensity of resort and urban development and bioarchaeological research in this part of the western Pacific. "Contract" reports on skeletal remains are typically unpublished, limited in scope, difficult to locate and often known of only by word of mouth. Hanson (1993), and Hanson and Butler (this issue) survey most of the earlier published and unpublished literature on the human biology of the Chamorros including work by Hanson and co-workers (Hanson, 1988, 1990, 1993; Hanson and Gordon, 1989).

The skeletal series used in the present study (Fig. 1) represent a total of 383 individuals, primarily the result of a number of cultural resource management projects in the Mariana Islands which were undertaken between approximately 1978 and 1994. The majority of these skeletal remains are from the transitional pre-Latte period (AD 1–1000) and Latte (AD 1000–1521) periods. All the data were recorded by Pietrusewsky and/or his students, including the co-authors of this paper, thus mitigating the problems associated with the lack of standardized recording and reporting procedures. A complete list of the skeletal series investigated, including samples sizes, approximate chronological dates, and appropriate references for each, is given in Table 1.

Without question, most of the skeletal series utilized in this study suffer from environmental, cultural, archaeological, and mortality bias as outlined in Wood et al. (1992), the so-called "osteological paradox." Hanson (1988 and Hanson and Butler (this issue) provide very useful comments on bone preservation and other mortuary practices that affect skeletal series from the Marianas. We are further cognizant of the fact that these are the only assemblages from the Marianas available for study. Perhaps the most difficult and elusive bias in these bioarchaeological series is that introduced by biological mortality bias, that is, the selective mortality is responsible for producing greater frequencies of stress indicators in skeletal assemblages than in living peoples due to the frailty and differential

TABLE 2. Age and sex distribution of Mariana skeletal series

Skeletal series[1]	Frequency of subadults n/N	%	Frequency of adults n/N	%	No. of M	No. of F	Adult sex ratio[2]	No. of adults[3] Y	M	O	A
Matapang, Guam	2/20	10.0	18/20	90.0	10	8	125.0	5	9	—	4
Fujita, Guam	4/28	14.3	24/28	85.7	12	9	133.3	10	4	—	10
Right-of-Way, Guam	6/16	37.5	10/16	62.5	4	6	66.7	2	6	1	1
Apurguan, Guam	51/152	33.6	101/152	66.4	53	43	123.3	38	37	13	13
Leo Palace, Guam	11/27	40.7	16/27	59.3	10	5	200.0	5	5	2	4
Academy Gym, Guam	1/4	25.0	3/4	75.0	2	1	200.0	1	1	—	1
Songsong, Rota	2/12	16.7	10/12	83.3	1	9	11.1	5	3	1	1
SNM Hotel, Rota	1/2	50.0	1/2	50.0	1	0	—	1	—	—	—
Latte House, Tinian	3/6	50.0	3/6	50.0	0	3	—	1	1	1	—
Marianas High School, Tinian	2/5	40.0	3/5	60.0	1	2	50.0	2	—	1	—
Grotto Site, Saipan	0/2	0.0	2/2	100.0	1	1	100.0	1	—	1	—
San Antonio, Saipan	1/33	3.0	32/33	97.0	—	—	—	15	6	6	5
Hafa Dai, Saipan	1/20	5.0	19/20	95.9	12	6	200.0	4	11	3	1
Oleai, Saipan	5/35	14.3	30/35	85.7	19	10	190.0	9	13	2	6

[1] See Table 1 for references.
[2] Sex ratio = proportion of males to females (M/F $\times$ 100).
[3] Y = young adult, M = middle-aged, O = old adult, A = adult.

susceptibility to disease and death (Wood et al., 1992). Saunders and Hoppa (1993) in their attempt to address these problem have concluded that problems of method and paleodemographic reconstruction are as great as the problem of biological mortality bias. Others (e.g., Goodman, 1993) have replied to the frailty argument and championed the use of multiple indicators of stress and a population (not individual) approach, one which is closer to the approach used in this paper.

METHODS

A full discussion of the methods used to determine age, sex, and stature and to record paleopathology, including skeletal and dental indicators, summarized in this paper, may be found in Pietrusewsky et al. (1992). Additional comments will be introduced in the appropriate section when discussing the results. The chi-square statistic and, where appropriate, Yates' correction for continuity were used to test for significant differences (Thomas, 1986).

INDICATORS OF HEALTH IN CHAMORRO SKELETAL REMAINS

Paleodemography

Some of the paleodemographic features and life tables for the Mariana skeletal series are presented in this section (Tables 2–6). The overall reliability of any paleodemographic reconstruction greatly depends upon the accuracy of the age and sex estimates and the representativeness of the sample (Ubelaker, 1989). Small sample sizes, underrepresentation of subadults, and underaging of adults is evident for several of the skeletal series presented in these tables. For example, according to Weiss (1973), subadults are adequately represented in the Apurguan sample (33.6%) and underrepresented at Oleai (14.3%). There are also great disparities in the proportion of adult males and adult females (sex ratio) in the series compared. There are nearly twice as many adult males as females in the Leo Palace, Hafa Dai, and Oleai samples. Only in the Songsong Village series do females predominate (nine females: one male). These discrepancies in sex class representation may be explained by the mortuary practices of the prehistoric Chamorros [see Hanson (1993) for a review of these], taphonomic processes, and/or collector bias. Only three of the skeletal series presented in Table 2—Apurguan, Leo Palace, and Oleai—are sufficiently large and have adequate representation of subadults to warrant close scrutiny. Further discussion of the paleodemographic features of the Mariana Islands will concentrate on these latter skeletal series. The remaining series are presented merely to provide information on the minimum number of individuals represented and the age-sex composition of these samples.

TABLE 3. Some paleodemographic features and estimators

	Apurguan	Leo Palace	Oleai
Average adult age[1]	43.5	41.3	39.4
n[2]	146.98	26.00	34.99
e_x^o at birth[3]	28.56	26.39	33.71
Juvenile/adult ratio[4] (JA)	0.178	0.125	0.103
Mean childhood mortality[5] (MCM)	0.071	0.085	0.042
D30/D5+[6]	0.581	0.560	0.714
D20/D5+[7]	0.802	0.762	0.879
Dependency ratio[8]	0.582	0.556	0.283

[1] Average age of adults is based on individuals ≥20 years; the average adult age is calculated from the age/sex table and excludes broadly aged adults (adults, young adults, middle-aged adults, etc.).
[2] n = Total number of individuals used to construct the life table.
[3] e_x^o = Life expectancy at birth.
[4] JA = Proportion of individuals aged 5–15 to individuals aged 20+ years; calculated from the life table.
[5] MCM = Average mortality for age intervals 5–10, 10–15, and 15–20; calculated from the life table.
[6] D30/D5+ = Proportion of individuals who live beyond 30 years to those who survive 5 years; calculated from the life table.
[7] D20/D5+ = Proportion of individuals who live beyond 20 years to those who survive 5 years; calculated from the life table.
[8] Dependency ratio = Proportion of dependents (individuals newborn–15 years plus those ≥50 years) to workers (individuals 15–50 years); calculated from the life table.

Abridged life tables. Abridged life tables are constructed for three of the largest Mariana skeletal series surveyed (Tables 4–6). Although the same limitations of demographic reconstruction discussed above apply to life tables (e.g., Bocquet-Appel and Masset, 1982; Howell, 1982; Sattenspiel and Harpending, 1983; Milner et al., 1989), mortality data provide a convenient and standard way of summarizing paleodemographic information of past populations and allow comparisons to be made. The age intervals used in these tables were adapted from the age and sex distribution tables in the original reports. Some of the younger age intervals in these tables have been collapsed to avoid values of zero in any of the cohorts. Adults whose exact age is unknown were evenly distributed among the more exact age categories in the table (Jackes, 1992). Among the demographic statistics represented in these tables are the actual number of deaths (D_x), survivorship rate (l_x), mortality rate (q_x), age-specific death rate (m_x), and life expectancy (e_x^o).

The life expectancy (e_x^o) at birth is highest at Oleai (33.71 years) and lowest in Leo Palace (26.39 years). In Apurguan, the largest and probably the most representative of a stable cemetery in these series, life expectancy at birth is 28.56 years. The high life expectancy at birth for the Oleai sample is due to the absence of observed deaths between birth and 3 years of age. The life expectancy for Oleai in the first age interval with observed deaths (3–5 years) is 30.71 years and at age 15 it is 22.98. Comparable life expectancies at age 15 are observed for Apurguan (21.88) and Leo Palace (19.38). The survivorship curves (Fig. 2) for Apurguan and Leo Palace are similar, in contrast to that for Oleai.

Figure 3 pictorially represents mortality for these three skeletal series. The mortality rate (q_x) of the Apurguan subadult population is high at the 2–5 year (.1000) and 5–10 year (.1032) intervals. Mortality is high in the 3–5 year age interval (0.1250) for Leo Palace. At Oleai the lack of subadults is a major factor of the low mortality rate. At Apurguan the probability of dying for adults steadily increases after 25 years of age and is high for those 45–50 years (q_x = .5000) and above. The same observation is generally evident for Leo Palace. For adults at Oleai the probability of dying is high during the 35–40 year (.2311), 40–45 year (.4403) and especially at 45–50 year (.6617) age intervals. The average adult age for these three series is 43.5 years (Apurguan), 39.4 years (Oleai), and 41.3 years (Leo Palace).

Estimators. In an attempt to circumvent the problems associated with underrepresentation of subadults and inaccurate aging of adults, various estimators have been proposed (Jackes, 1992). Among these are the juvenile/adult ratio, mean childhood mortality, D30/D5+ ratio, and D20/D5+ ratio. The estimators for the three largest series are given in Table 3.

Juvenile-adult ratio (JA). The JA ratio is the ratio of the number of individuals aged 5–14.9 years divided by the number of adults over the age of 20 years (5–14.9/20+). Using data in the life tables, the JA ratio in these series ranges from 0.103 (Oleai) to 0.178 (Apurguan), values which are low when compared to those calculated for a large number of historical and archaeological sites (Jackes, 1992).

TABLE 4. Abridged life table for burials from Apurguan, Guam

x	n_x	D_x	d_x	l_x	q_x	L_x	m_x	T_x	e_x^o
0–2	2	7	4.76	100.00	0.0476	195.24	0.0244	2856.19	28.56
2–5	3	14	9.53	95.24	0.1000	271.42	0.0351	2660.95	27.94
5–10	5	13	8.84	85.71	0.1032	406.45	0.0218	2389.53	27.88
10–15	5	5	3.40	76.87	0.0443	375.83	0.0091	1983.08	25.80
15–20	5	7	4.76	73.47	0.0648	355.42	0.0134	1607.24	21.88
20–25	5	9.9	6.74	68.70	0.0980	326.68	0.0206	1251.82	18.22
25–30	5	17.9	12.18	61.97	0.1965	279.39	0.0436	925.14	14.93
30–35	5	14.9	10.14	49.79	0.2036	223.60	0.0453	645.75	12.97
35–40	5	16.07	10.93	39.65	0.2757	170.92	0.0640	422.15	10.65
40–45	5	12.07	8.21	28.72	0.2860	123.06	0.0667	251.22	8.75
45–50	5	15.07	10.25	20.51	0.5000	76.90	0.1333	128.16	6.25
50–60	10	15.07	10.25	10.25	1.0000	51.27	0.2000	51.27	5.00
Total		146.98							

x = Age interval in years. n_x = Width of age interval x. D_x = Actual numbers of observed deaths at age x. d_x = Number of individuals dying at age x, based on a cohort of 100. l_x = Survivorship at age x. q_x = Mortality rate or probability of dying at age x. L_x = Number of years lived between age x and $x + 1$. m_x = Age specific death rate for age interval x. T_x = Total number of years lived beyond age x. e_x^o = Expectation of life at age interval x (life expectancy).
Thirty-eight adults (10 adults, 10 young adults, 15 middle-aged adults, and 3 middle-old-aged adults) were distributed evenly to the appropriate age categories.

Mean childhood mortality (MCM). Highly correlated to JA ratio, the MCM is based on the q values of childhood, specifically the mean of childhood mortality for the 5–10, 10–15, and 15–20 age intervals. This mean mortality quotient is not affected by infant representation, thus avoiding the problem of infant underrepresentation. The MCM is low for all three skeletal series (Jackes, 1992). Using this estimator, the fertility rate for Apurguan is estimated to be about five children born to each woman who survived to age 15 to 45 years. A slightly higher fertility rate of 6.6 children is observed for Leo Palace and a much lower rate of 3.8 is observed for Oleai. The two series from Guam have a relatively healthy fertility rate and barring any disasters, the populations should have been experiencing an increase in numbers, the kind of steady increase expected for an island ecosystem.

D30/D5 ratio. The D30/D5+ ratio, which serves as a crude measure of fertility in a population (Buikstra et al., 1986), represents the number of deaths over 30 years of age divided by those who survive to 5 years and older. The values for Apurguan (.581) and Leo Palace (.560) are similar while the value for Oleai is much higher (.714). Owing to the difficulties in dividing the age of a population at 30, Konigsberg et al. (1989)

TABLE 5. Abridged life table for burials from Leo Palace, Naton Beach, Guam

x	n_x	D_x	d_x	l_x	q_x	L_x	m_x	T_x	e_x^o
0–1	1	2	7.69	100.00	0.0769	96.15	0.0800	2639.33	26.39
1–3	2	0	0.00	92.31	0.0000	184.62	0.0000	2543.17	27.55
3–5	2	3	11.54	92.31	0.1250	173.08	0.0667	2358.56	25.55
5–10	5	1	3.85	80.77	0.0476	394.23	0.0098	2185.48	27.06
10–15	5	1	3.85	76.92	0.0500	375.00	0.0103	1791.25	23.29
15–20	5	3	11.54	73.08	0.1579	336.54	0.0343	1416.25	19.38
20–25	5	1.62	6.23	61.54	0.1013	292.12	0.0213	1079.71	17.55
25–30	5	2.62	10.08	55.31	0.1822	251.35	0.0401	787.60	14.24
30–35	5	2.62	10.08	45.23	0.2228	200.96	0.0501	536.25	11.86
35–40	5	2.95	11.35	35.15	0.3228	147.40	0.0770	335.29	9.54
40–45	5	2.95	11.35	23.81	0.4766	90.67	0.1251	187.88	7.89
45–50	5	0.95	3.65	12.46	0.2932	53.17	0.0687	97.21	7.80
50–60	10	2.29	8.81	8.81	1.0000	44.04	0.2000	44.04	5.00
Total		26.00							

x = Age interval in years. n_x = Width of age interval x. D_x = Actual numbers of observed deaths at age x. d_x = Number of individuals dying at age x, based on a cohort of 100. l_x = Survivorship at age x. q_x = Mortality rate or probability of dying at age x. L_x = Number of years lived between age x and $x + 1$. m_x = Age specific death rate for age interval x. T_x = Total number of years lived beyond age x. e_x^o = Expectation of life at age interval x (life expectancy).
Eight adults (2 adults, 3 young adults, 1 middle-aged adult, and 2 middle-old-aged adults) were distributed evenly to the appropriate age categories.

TABLE 6. Abridged life table for burials from Oleai, Saipan

x	n_x	D_x	d_x	l_x	q_x	L_x	m_x	T_x	e^o_x
0–1	1	0	0.00	100.00	0.0000	100.00	0.0000	3370.96	33.71
1–3	2	0	0.00	100.00	0.0000	200.00	0.0000	3270.96	32.71
3–5	2	2	5.72	100.00	0.0572	194.28	0.0294	3070.96	30.71
5–10	5	1	2.86	94.28	0.0303	464.28	0.0062	2876.68	30.51
10–15	5	2	5.72	91.43	0.0625	442.84	0.0129	2412.40	26.39
15–20	5	1	2.86	85.71	0.0333	421.41	0.0068	1969.56	22.98
20–25	5	3.71	10.60	82.85	0.1280	387.75	0.0273	1548.16	18.69
25–30	5	1.71	4.89	72.25	0.0676	349.03	0.0140	1160.40	16.06
30–35	5	4.96	14.18	67.36	0.2104	301.37	0.0470	811.37	12.04
35–40	5	4.30	12.29	53.19	0.2311	235.21	0.0522	510.00	9.59
40–45	5	6.30	18.01	40.90	0.4403	159.47	0.1129	274.79	6.72
45–50	5	5.30	15.15	22.89	0.6617	76.59	0.1978	115.32	5.04
50–60	10	2.71	7.75	7.75	1.0000	38.73	0.2000	38.73	5.00
Total		34.99							

x = Age interval in years. n_x = Width of age interval x. D_x = Actual numbers of observed deaths at age x. d_x = Number of individuals dying at age x, based on a cohort of 100. l_x = Survivorship at age x. q_x = Mortality rate or probability of dying at age x. L_x = Number of years lived between age x and $x + 1$. m_x = Age specific death rate for age interval x. T_x = Total number of years lived beyond age x. e^o_x = Expectation of life at age interval x (life expectancy).
Sixteen adults (5 adults, 3 young adults, 7 middle-aged adults, and 1 30–48-year-old) were distributed evenly to the appropriate age categories.

have suggested that the D20/D5+ statistic be used in future work. In the Mariana skeletal series, the range for this statistic is .762 (Leo Palace) to .879 (Oleai).

Dependency ratio. The dependency ratio, or the number of dependents supported by each worker in a population, is calculated as the sum of the number of individuals aged less than 15 years and ≥50 years (the dependents) divided by the number of individuals between 15 and 50 years (the workers) (Howell, 1982). Using information from the life tables, the dependency ratio for two of the skeletal series, Apurguan and Leo Palace, are similar. In these two series approximately two workers were needed to support one dependent. Because of the few subadults in the Oleai sample, a much lower dependency ratio (0.283) was obtained for the series. Here four workers are required to support every one dependent.

In summary, while sample size is small in these series, especially in the Oleai and Leo Palace populations, the representation of

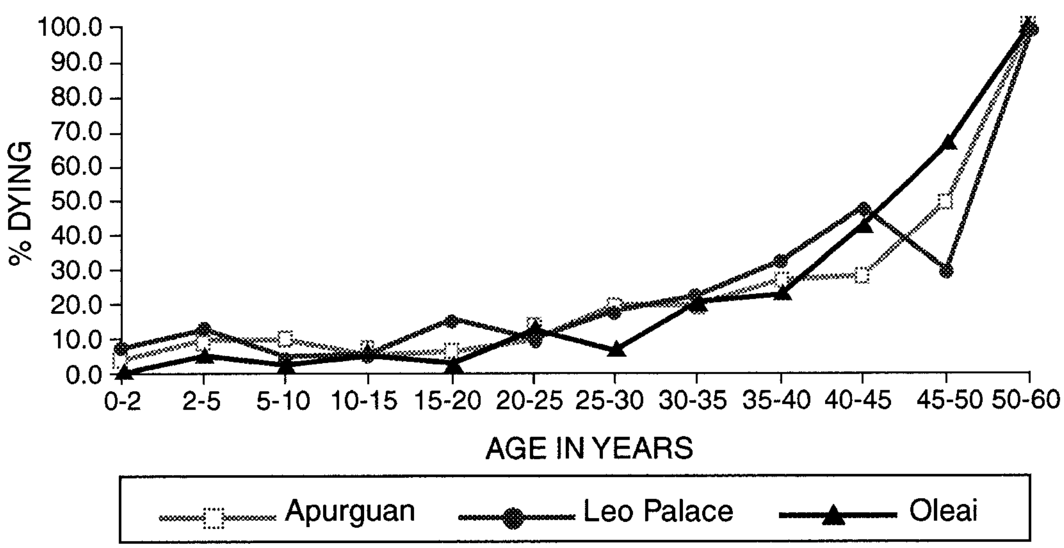

Fig. 2. Mortality curves for three Mariana skeletal series.

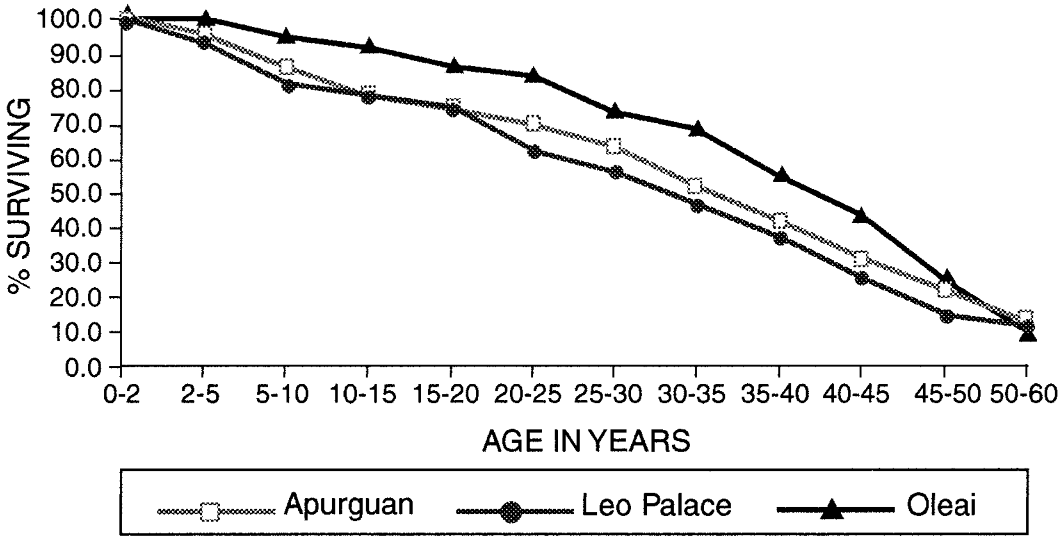

Fig. 3. Survivorship curves for three Mariana skeletal series.

subadults and adults, as well as the ratio of males and females, in the Apurguan and Leo Palace samples indicate that these two series probably represent long-term cemetery populations. Females are underrepresented in all three sites and over 27% of the subadult deaths occur in the 3–5 year age interval. Most of the female deaths occur after 45 years of age and the probability of death is high at 45–50 years. In the Oleai sample subadults are underrepresented and most male deaths occur at 20–25, 30–35, and 40–45 year intervals, while at Apurguan most of the males died at 25–30 years, possibly due to warfare. The average life expectancy at birth for the three series is approximately 27 years. Calculation of various estimators, while emphasizing fertility rather than mortality, indicates a healthy fertility rate for these series.

Stature

Stature estimates calculated here are based on formulae for Polynesian Maori (Houghton et al., 1975) and complete long limb bones. If more than one stature estimate was calculated, the estimate having the least error was selected. Currently, there are no stature regression formulae that have been computed specifically for Chamorro remains. The mean estimated statures reported in Tables 7 and 8 are based on a very limited number of individuals. The largest sample is Apurguan, where the range in male mean stature is 170.1–176 cm, or 5′7″–5′9″. The mean stature for all prehistoric Mariana males surveyed is 173.1 cm. According to Martin's classification (see Olivier, 1969), the stature for male Chamorros falls in the lower to middle range of the "tall" range. In females (Table 8), the range in mean stature is 158.9–163.7 cm, or 5′2.5″–5′4″. The mean stature for Mariana females is 161.3 cm. Female Chamorro statures fall in the medium to tall range according to the same scheme used to classify male stature. The average stature for Apurguan females is very similar to other female Chamorro series compared, the range for seven female series is 154.9–163.5 cm. There are no apparent interisland differences in stature.

Stature for living Chamorros (from Saipan) and other Micronesian groups has been reported by K. Hasebe (see Hunt, 1950a, 1950b). The average stature for living male Chamorros from Saipan is 163 cm, a value which falls in the submedium stature classification according to Martin. The stature estimates for skeletal (prehistoric) Chamorro series, reported in Tables 7 and 8, are considerably taller than those reported by Hasebe for living Chamorros from Saipan.

TABLE 7. Comparison of male stature[1] (cm) in the Mariana skeletal series

Skeletal series[2]	N	Mean	Minimum	Maximum
Matapang, Guam	2	176	175	177
Fujita, Guam	1	174	—	—
Apurguan, Guam	15	172.4	167.8	177.1
Leo Palace, Guam	2	170.1	166.8	172.8
SNM Hotel, Rota	1	171.1	—	—
Unai Chulu, Tinian[3]	1	172.9	—	—
San Antonio, Saipan[4]	2	175.4	173.2	177.5
Hafa Dai, Saipan[3]	7	174.4	170.6	179.2
Oleai, Saipan	2	173.5	172.3	174.6
Mariana series[5]	33	173.1	166.8	174.6

[1] Estimated statures were calculated on complete long limb bones using Houghton et al. (1975) Polynesian Maori regression formulae.
[2] See Table 1 for references.
[3] Estimated stature is based on the right femur.
[4] Estimated stature is based on the humerus.
[5] Mean stature for the Mariana Series is calculated from individual statures.

Stature estimates for other living male Micronesians, including Palau, Yap, Chuuk, Mortlocks, Kusaie, Marshall Island and Pingelap range from 160 to 164 cm [see Howells (1970) for a summary of this anthropometric information taken from K. Hasebe]. Quite interestingly, very similar average statures (males = 172.4 cm; females = 162.9 cm) have been reported for prehistoric Hawaiians (Pietrusewsky and Douglas, 1994).

Dental enamel hypoplasia

Dental enamel hypoplasia results from a disturbance of the enamel development in the growing deciduous or permanent tooth bud (phase of amelogenesis). The causes of the hypoplastic defects are commonly attributed to a variety of factors including physiological stress and infectious diseases (Goodman et al., 1980; Goodman and Rose, 1991; Lukacs, 1989). The data reported here (Table 9) include most manifestations of dental enamel hypoplasia, e.g., pits, band, depressions or discoloration of the surface, but linear hypoplasias are the most frequently observed defects in these remains. Only defects observed in the permanent incisors and canines are reported. The presence of betel staining on some of the teeth in these series makes observations of hypoplastic defects difficult and the frequencies reported are likely to underestimate the actual frequencies.

TABLE 8. Comparison of female stature[1] (cm) in the Mariana skeletal series

Skeletal series[2]	N	Mean	Minimum	Maximum
Apurguan, Guam	7	162.8	156.7	168.4
Leo Palace, Guam	1	159.0	—	—
Songsong, Rota	7	161	159	166
Latte House, Tinian	2	163.7	163.5	163.8
San Antonio, Saipan[3]	2	159.2	153.9	164.4
Hafa Dai, Saipan[4]	2	161.7	160.2	163.1
Oleai, Saipan	2	158.9	154.9	162.9
Mariana series[5]	23	161.3	159	168.4

[1] Estimated statures were calculated on complete long limb bones using Houghton et al. (1975) Polynesian Maori regression formulae.
[2] See Table 1 for references.
[3] Estimated stature is based on the left femur.
[4] Estimated stature is based on the humerus.
[5] Mean stature for the Mariana Series is calculated from individual statures.

The total frequency of occurrence of dental enamel hypoplasia in the Mariana permanent incisors and canines sampled is 32.5% (Table 9). The difference between the adult male total (34.2%) and the adult female total (30.2%) is not statistically significant ($\chi^2 = 0.640$, $P > .05$). Higher frequencies of occurrence of enamel hypoplasia are observed in adult males than in adult females in the Fujita ($\chi^2_c = 4.822$, $P > .05$) and Leo Palace ($\chi^2_c = 17.368$, $P > .05$) series, differences which are statistically significant. In the Apurguan sample, however, the reverse is true; enamel hypoplasias are significantly more common in females (37.3%) than in males (22.2%), suggesting that small sample size may be skewing the results in the former series.

The differences in the total incidence of dental enamel hypoplasia between Apurguan, the largest of the series compared, and the other samples from Guam, Rota, and Saipan are not statistically significant ($\chi^2 = 0.670$, $P > .05$). However, significant differences are found between Oleai and Guam Island ($\chi^2 = 19.424$, $P \leq .01$), and between Oleai and Rota Island ($\chi^2 = 5.168$, $P \leq .05$). No statistically significant difference was observed in the incidence of enamel hypoplasia between Guam Island and Rota Island ($\chi^2_c = 1.535$, $P > .05$). With a caveat for small sample size, these findings are suggestive of increased stress (environmental, nutritional, infectious, etc.) in the precontact inhabitants on Saipan, which is mitigated on the larger island of Guam, and perhaps Rota by propinquity. Support for this hypothesis comes from comparison of

TABLE 9. Frequency of occurrence of dental enamel hypoplasia[1] in permanent canines and incisors of Mariana Island samples

	Male		Female		?Sex		Total (M+F+?)	
Skeletal series[2]	A/O	%	A/O	%	A/O	%	A/O	%
Matapang, Guam	0/2	0.0	0/14	0.0	—	—	0/16	0.0
Fujita, Guam	19/43	44.2	4/26	15.4	0/9	0.0	23/78	29.5
Right-of-Way, Guam	0/12	0.0	0/1	0.0	—	—	0/13	0.0
Apurguan, Guam	24/108	22.2	31/83	37.3	55/151	36.4	110/342	32.2
Leo Palace, Guam	15/15	100.0	1/10	10.0	12/40	30.0	28/65	43.1
Academy Gym, Guam	—	—	0/6	0.0	—	—	0/6	0.0
Guam total	58/180	32.2	36/140	25.7	67/200	33.5	161/520	31.0
Songsong Village, Rota	—	—	12/19	63.2	—	—	12/19	63.2
SNM Hotel, Rota	0/11	0.0	—	—	—	—	0/11	0.0
Rota total	0/11	0.0	12/19	63.2	—	—	12/30	40.0
Oleai, Saipan	11/11	100.0	—	—	11/21	52.4	22/32	68.8
Mariana total	69/202	34.2	48/159	30.2	78/221	35.3	183/563	32.5

[1] Any expression of hypoplastic defect in canines and incisors.
[2] See Table 1 for references.

the Mariana frequency of dental enamel hypoplasia (32.5%) with that for prehistoric Hawaiians (7.7%), a difference which is statistically significant ($\chi^2 = 238.346$, $P \leq .01$).

Cribra orbitalia

Porotic hyperostosis and cribra orbitalia, a porosis of the orbital roof, are commonly attributed to iron-deficiency anemia (Steinbock, 1976; Stuart-Macadam, 1992). Due to the almost complete absence of subadults in the series available for study, the frequencies of occurrence of cribra orbitalia are reported per adult individual (Table 10). No examples of cribra orbitalia were observed in any of the adult female eye sockets (0/45), while in adult males the frequency of occurrence is 20.3%, a significant difference ($\chi^2_c = 8.450$, $P \leq 0.01$). A significant difference in cribra orbitalia is found when males from Apurguan (1/17, or 5.9%) and the rest of the Guam (2/8, or 25.0%) are compared ($\chi^2_c = 4.461$, $P \leq 0.05$).

The overall prevalence of cribra orbitalia in adults is 11.3%. The frequency of cribra orbitalia in the skeletal remains from Apurguan is very low (3.6%). There are no significant differences in the incidence of cribra orbitalia in adults between Guam (7.1%) and Rota (12.5%) islands ($\chi^2_c = 1.495$, $P > 0.05$), between Guam (7.1%) and Saipan (16.0%) ($\chi^2_c = 2.646$, $P > 0.05$) or between Saipan (16.0%) and Rota (12.5%) ($\chi^2_c = 0.074$, $P > 0.05$).

No statistically significant differences are found when cribra orbitalia in adult Mariana Islanders (11.5%) and adult prehistoric Hawaiians (13.5%) are compared ($\chi^2 = 0.309$, $P > .05$). Small sample size must be taken into consideration in interpreting these results but it would appear that in general, the skeletal populations from the Mariana Islands did not suffer greatly from iron deficiency anemia. The absence of cribra orbitalia in female orbits may be due to small sample size, or alternatively, differential susceptibility, or differential abilities to recover, remodel and/or survive, between the sexes (see e.g., Stuart-Macadam, 1995).

Limb bone fractures

Fractures of the adult long limb bones (Table 11) provide an indication of the frequency and type of traumatic, accidental or deliberate, injury in a population (Walker, 1989). Although healed fractures of other bones in the skeleton are observed in Mariana skeletal series, because of difficulties in establishing frequencies in these kinds of fractures, we are concentrating on the long limb bones. Fracture frequency is estimated using the corresponding number of complete, or nearly complete, bones reported. The overall frequency of limb bone fractures in the Mariana remains is 0.6% (5/847), a relatively low frequency. The long limb bones which exhibit healed fractures in the Mari-

TABLE 10. Frequency of occurrence of cribra orbitalia in comparative Mariana skeletal series (reported by individual)

	Adult males		Adult females		Adults		Subadults		Total	
Skeletal series[1]	A/O	%	A/O	%	A/O	%	A/O	%	A/O	%
Matapang, Guam	—	—	0/1	0.0	0/1	0.0	—	—	0/1	0.0
Fujita, Guam	1/1	100.0	0/1	0.0	1/2	50.0	—	—	1/2	50.0
Right-of-Way, Guam	0/2	0.0	0/2	0.0	0/4	0.0	—	—	0/4	0.0
Apurguan, Guam	1/17	5.9	0/11	0.0	1/28	3.6	0/2	0.0	1/30	3.3
Leo Palace, Guam	1/4	25.0	0/1	0.0	1/5	20.0	—	—	1/5	20.0
Academy Gym, Guam	0/1	0.0	0/1	0.0	0/2	0.0	—	—	0/2	0.0
Guam total	3/25	12.0	0/17	0.0	3/42	7.1	0/2	0.0	3/44	6.8
Songsong Village, Rota	—	—	0/7	0.0	0/7	0.0	—	—	0/7	0.0
SNM Hotel, Rota	1/1	100.0	—	—	1/1	100.0	—	—	1/1	100.0
Rota total	1/1	100.0	0/7	0.0	1/8	12.5	—	—	1/8	12.5
Latte House Site, Tinian	—	—	0/3	0.0	0/3	0.0	—	—	0/3	0.0
Marianas High, Tinian	—	—	0/1	0.0	0/1	0.0	—	—	0/1	0.0
Tinian total	—	—	0/4	0.0	0/4	0.0	—	—	0/4	0.0
Grotto Site, Saipan	1/1	100.0	—	—	1/1	100.0	—	—	1/1	100.0
San Antonio, Saipan	1/7	14.2	0/6	0.0	1/13	7.7	—	—	1/13	7.7
Hafa Dai Beach, Saipan	5/8	62.5	0/1	0.0	5/9	55.6	—	—	5/9	55.6
Oleai, Saipan	1/17	5.9	0/10	0.0	1/27	3.7	—	—	1/27	3.7
Saipan total	8/33	24.2	0/17	0.0	8/50	16.0	—	—	8/50	16.0
Mariana total	12/59	20.3	0/45	0.0	12/104	11.5	0/2	0.0	12/106	11.3

[1] See Table 1 for references.

ana remains are the humerus (one), radius (one), ulnae (two), and femur (one). All examples of healed limb bone fractures are confined to three sites on Guam. The frequency of occurrence of limb bone fractures in Apurguan, the largest skeletal series compared, is 0.7%, a frequency which approximates the total for all the Marianas. By contrast, the combined frequency of limb bone fractures in precontact Hawaiian skeletal remains is 1.6%, a prevalence which is significantly greater ($\chi^2 = 5.465, P \leq 0.05$) than that observed in the Marianas skeletal series. Accidental or deliberate injury, as indicated by limb bone fracture, is of a very low occurrence in the prehistoric Mariana Islanders.

Spondylolysis

Spondylolysis, or fracture of the lumbar vertebrae at the *pars interarticularis* (the narrow area connecting the inferior facets of the neural arch with the superior facets), has been related to repeated stress to the lower lumbar vertebrae by physical activities requiring flexion of the lumbar spine with the legs extended (Merbs, 1989; Ortner and Putschar, 1981). More recently, Arriaza (1995) has proposed that hyperextension of the lower back under stressful conditions as another explanation for spondylolysis. A genetic predisposition for stress fractures in the lower back has also been advanced. The overall frequency of occurrence of spondylolysis in the lumbar vertebrae from the Marianas is 4.3% (Table 12). All examples of spondylolysis occur in the skeletal series from Guam, but sample sizes from the other islands, Tinian, Saipan, and Rota, are small. In the Leo Palace remains, the prevalence of spondylolysis is greater in females (25%) than in males (5.9%), a difference which is statistically significant ($\chi^2_c = 4.488, P \leq 0.05$). For the Apurguan series, all cases of spondylolysis are in males. When the three series from Guam—Apurguan, Leo Palace, and Academy Gym—are combined, there is no significant difference between adult males (7.5%) and females (1.4%) ($\chi^2_c = 2.107, P > .05$). A significantly lower frequency of occurrence of spondylolysis (1.5%) is observed in a large prehistoric Hawaiian skeletal series from Maui (Pietrusewsky et al., 1991) ($\chi^2_c = 6.885, P \leq 0.01$).

Degenerative osteoarthritis

Degenerative osteoarthritis is characterized by the progressive formation of osteo-

TABLE 11. Frequency of occurrence of limb bone fractures in the adult Mariana Island skeletons

Skeletal series[1]	Clavicle		Humerus		Radius		Ulna		Femur		Tibia		Fibula		Total	
	A/O	%	A/O	%	A/O	%	A/O	%	A/O	%	A/O	%	A/O	%	A/O	%
Matapang	0/3	0.0	0/7	0.0	0/4	0.0	0/5	0.0	0/7	0.0	0/9	0.0	0/12	0.0	0/47	0.0
Fujita	0/4	0.0	0/6	0.0	0/9	0.0	0/9	0.0	0/7	0.0	0/4	0.0	0/4	0.0	0/43	0.0
Right-of-Way	0/6	0.0	0/6	0.0	1/5	20.0	0/5	0.0	0/5	0.0	0/2	0.0	0/3	0.0	1/32	3.1
Apurguan	0/66	0.0	0/68	0.0	0/68	0.0	2/64	3.1	1/48	2.1	0/47	0.0	0/54	0.0	3/415	0.7
Leo Palace	0/8	0.0	1/10	10.0	0/6	0.0	0/10	0.0	0/5	0.0	0/7	0.0	0/6	0.0	1/52	1.9
Academy Gym	0/1	0.0	—	—	0/1	0.0	0/1	0.0	—	—	—	—	0/1	0.0	0/4	0.0
Guam total	0/88	0.0	1/97	1.0	1/93	1.1	2/94	2.1	1/72	1.4	0/69	0.0	0/80	0.0	5/593	0.8
Songsong	0/11	0.0	0/12	0.0	0/15	0.0	0/13	0.0	0/13	0.0	0/11	0.0	0/10	0.0	0/85	0.0
SNM Hotel	0/2	0.0	0/2	0.0	0/2	0.0	0/2	0.0	—	—	—	—	—	—	0/8	0.0
Rota total	0/13	0.0	0/14	0.0	0/17	0.0	0/15	0.0	0/13	0.0	0/11	0.0	0/10	0.0	0/93	0.0
Latte House	0/3	0.0	0/5	0.0	0/4	0.0	0/4	0.0	0/4	0.0	0/4	0.0	0/4	0.0	0/28	0.0
Unai Chulu[2]	—	—	0/2	0.0	0/1	0.0	—	—	0/1	0.0	—	—	—	—	0/4	0.0
Tinian total	0/3	0.0	0/7	0.0	0/5	0.0	0/4	0.0	0/5	0.0	0/4	0.0	0/4	0.0	0/32	0.0
Mariana High	—	—	0/1	0.0	—	—	—	—	0/1	0.0	—	—	—	—	0/2	0.0
Grotto Site	0/3	0.0	0/1	0.0	0/1	0.0	0/2	0.0	0/2	0.0	—	—	—	—	0/9	0.0
San Antonio[2]	—	—	0/4	0.0	0/2	0.0	—	—	0/3	0.0	0/3	0.0	—	—	0/12	0.0
Hafa Dai[2]	0/4	0.0	0/3	0.0	0/7	0.0	0/5	0.0	0/14	0.0	0/9	0.0	—	—	0/42	0.0
Oleai	0/15	0.0	0/7	0.0	0/10	0.0	0/9	0.0	0/8	0.0	0/8	0.0	0/7	0.0	0/64	0.0
Saipan total	0/22	0.0	0/16	0.0	0/20	0.0	0/16	0.0	0/28	0.0	0/20	0.0	0/7	0.0	0/129	0.0
Total	0/126	0.0	1/134	0.7	1/135	0.7	2/129	1.6	1/118	0.9	0/104	0.0	0/101	0.0	5/847	0.6

[1] See Table 1 for references.
[2] Observations made for complete bones only.

phytes or lipping around the edges of an articular joint surface, and/or loss of the normally smooth articular surface to ossific nodules, porosis or eburnation. These changes are associated with the normal wear and tear of living and are distinguished from traumatic arthritis which is related to the disruption of the biomechanical functioning of a joint. Each of the articular surfaces of the appendicular and vertebral skeleton was systematically scored for degenerative osteoarthritis on a none, slight, moderate, and marked scale, with only advanced observations reported here. The frequencies reported in Tables 13 and 14 reflect only moderate and marked expressions of lipping or porosis in the Mariana skeletal remains. The articular surfaces which have the greatest amount of arthritic involvement are in the knee, ankle, and shoulder (Table 13). This pattern of osteoarthritis varies little from site to site. The overall prevalence of advanced osteoarthritis in the Mariana appendicular skeletons is 9.1%.

When the Guam samples (except Apurguan) are combined (Table 14) there are significant differences in the total occurrence of advanced osteoarthritis when compared to those recorded in the Oleai sample ($\chi^2_c = 22.130$, $P \leq 0.01$). When Apurguan is compared with the other Mariana series ($\chi^2 = 12.148$, $P \leq 0.01$), the difference is also significant. The highest overall frequency of advanced osteoarthritis is observed in the Oleai series (21.4%), a frequency which probably reflects the older age-at-death of the individuals in this sample and its larger sample size compared to some of the other skeletal series compared.

A significantly ($\chi^2 = 48.146$, $P \leq 0.01$) greater incidence of osteoarthritis is observed in the Mariana series (9.1%) compared with prehistoric Hawaiians (Pietrusewsky and Douglas, 1994) where the frequency of occurrence of advanced osteoarthritis is 3.9%.

Vertebral osteoarthritis. Because of the functional differences in regions of the spine and the number and variety of joint surfaces of a vertebrae (body, facets), comparisons of vertebral osteoarthritis are very difficult. Tables 15 and 16 attempt to distill the data into a manageable size so that some conclusions may be drawn. The spine is divided into its three segments (cervical, thoracic

TABLE 12. Frequency of occurrence of spondylolysis[1] in the lumbar vertebrae from the Marianas

Series[2]	Male	Female	?Sex	Total (M+F+?)
Apurguan, Guam				
A/O	7/83	0/40	—	7/123
%	8.4	0.0		5.7
Leo Palace, Guam				
A/O	1/17	1/4	—	2/21
%	5.9	25.0		9.5
Academy Gym, Guam				
A/O	1/5	—	—	1/5
%	20.0			20.0
Guam total				
A/O	9/105	1/44	—	10/149
%	8.6	2.3		6.7
Songsong Village, Rota				
A/O	—	0/18	—	0/18
%		0.0		0.0
SNM Hotel, Rota				
A/O	0/2	—	—	0/2
%	0.0			0.0
Rota Total				
A/O	0/2	0/18	—	0/20
%	0.0	0.0		0.0
Hafa Dai, Saipan				
A/O	—	—	0/44	0/44
%			0.0	0.0
Oleai, Saipan				
A/O	0/13	0/7	—	0/20
%	0.0	0.0		0.0
Saipan Total				
A/O	0/13	0/7	0/44	0/64
%	0.0	0.0	0.0	0.0
Total				
A/O	9/120	1/69	0/44	10/233
%	7.5	1.4	0.0	4.3

[1] Complete separation and hemiseparation (one side).
[2] See Table 1 for references.

and lumbar) and, in the upper portion of the tables, observations of advanced osteoarthritic lipping (i.e. moderate and marked expressions) of the superior and inferior articulating processes are combined. The lower portion of the tables summarize advanced osteophytosis in the superior and inferior (here combined) vertebral bodies of the same vertebrae.

The overall frequency of occurrence of advanced osteoarthritis in the articular surfaces of presacral vertebrae in the Mariana Islands is 6.6% (Table 15). Comparing the different regions of the spine, the greatest involvement occurs in the lumbar region (12.4%) followed by the thoracic (6.8%) and cervical (2.4%) regions. This pattern is repeated in each of the skeletal series. Among the series compared, Oleai has the highest reported overall frequency (19.1%) of presacral articular osteoarthritis, a finding which is likely related to the older age-at-death of the sample. The frequency of occurrence of osteoarthritis in the articular surfaces of presacral vertebrae in Apurguan is 4.5%, a significantly lower frequency when compared to Oleai, a combined Saipan total, and the average of all remaining skeletal series (Table 16). A very similar level of advanced osteoarthritis (6.1%) is observed in prehistoric Hawaiians, a difference which is not significant ($P > .05$).

The overall frequency of occurrence of advanced lipping of the presacral vertebral bodies is 12.5%. There is only slightly greater involvement of the lumbar (14.1%) vertebrae followed by the cervical (12.8%) and thoracic (11.6%) vertebrae. The frequency of occurrence of lipping of the presacral vertebral centra is lowest in the Apurguan (0.9%) and the remaining series from Guam. The elevated frequencies of vertebral osteophytosis in the Hafa Dai series (44.3%) may reflect problems of standardization of this subjectively scored trait when these series were initially examined. The frequency of occurrence of osteophytosis in the Oleai series is 27.8%, a moderately high frequency of occurrence, which, again, reflects the higher age-at-death for this series.

No statistically significant difference in the level of osteophytosis is observed in the Apurguan and remaining series from Guam (Table 16). A significantly lower frequency (9.1%) of osteophytosis of the vertebral centra is observed in prehistoric Hawaiians ($\chi^2 = 13.828$, $P \leq .01$).

Dental pathology

Premortem tooth loss, dental caries, and abscessing in the remains from the Mariana Islands were recorded on a per tooth or tooth socket basis (Table 17). The loss of teeth before death has several etiologies indicative of pathological processes including periodontal disease, caries, and dental abscessing. Tooth loss attributable to intentional extraction of teeth is not included in these observations.

The overall frequency of occurrence of premortem tooth loss in the remains from

TABLE 13. Frequency of occurrence of advanced[1] appendicular osteoarthritis in Mariana skeletal series (sexes combined)[2]

Articular surface	Matapang		Fujita		Right-of-Way		Apurguan		Leo Palace		Academy Gym		SNM Hotel		Oleai		Total	
	A/O	%	A/O	%	A/O	%	A/O	%	A/O	%	A/O	%	A/O	%	A/O	%	A/O	%
Sterno-clavicular	0/2	0.0	—	—	0/1	0.0	1/23	4.3	0/4	0.0	—	—	0/1	0.0	0/2	0.0	1/33	3.0
Acromio-clavicular	—	—	0/1	0.0	0/1	0.0	1/8	12.5	0/4	0.0	—	—	0/1	0.0	1/4	25.0	2/19	10.5
Glenoid fossa	—	—	0/4	0.0	0/1	0.0	3/41	7.3	2/9	22.2	0/3	0.0	0/2	0.0	4/16	25.0	9/76	11.8
Humeral head	—	—	—	—	—	—	0/21	0.0	0/1	0.0	—	—	—	—	2/5	40.0	2/27	7.4
Radial head	0/1	0.0	1/3	33.3	0/5	0.0	2/49	4.1	0/10	0.0	0/1	0.0	0/2	0.0	0/8	0.0	3/79	3.8
Proximal ulna	0/4	0.0	3/6	50.0	0/3	0.0	3/65	3.1	0/11	0.0	0/2	0.0	0/2	0.0	1/8	12.5	7/101	8.9
Sacro-iliac	—	—	0/2	0.0	0/1	0.0	3/18	16.7	0/3	0.0	—	—	—	—	0/8	0.0	3/32	9.4
Acetabulum	0/3	0.0	0/3	0.0	0/2	0.0	0/29	0.0	0/6	0.0	0/3	0.0	0/2	0.0	5/17	29.4	5/65	7.7
Femoral head	0/4	0.0	0/2	0.0	—	—	0/17	0.0	0/7	0.0	—	—	—	—	0/5	0.0	0/35	0.0
Femoral condyle	—	—	0/4	0.0	—	—	4/30	13.3	1/5	20.0	—	—	—	—	2/6	33.3	7/45	15.6
Proximal tibia	—	—	0/1	0.0	—	—	1/26	3.9	1/5	20.0	—	—	—	—	3/4	75.0	5/36	13.9
Calcaneus	1/6	16.7	4/9	44.4	0/3	0.0	4/73	5.5	0/12	0.0	0/1	0.0	0/2	0.0	1/11	9.1	10/117	8.5
Talus	0/10	0.0	4/10	40.0	0/3	0.0	10/85	11.8	2/13	15.4	0/2	0.0	0/2	0.0	3/9	33.3	19/134	14.2
Temporo-mandibular	—	—	—	—	—	—	3/58	5.2	3/8	37.5	0/3	0.0	0/2	0.0	—	—	6/71	8.5
Total	1/30	3.3	12/45	26.7	0/20	0.0	35/543	6.4	9/98	9.2	0/15	0.0	0/16	0.0	22/103	21.4	79/870	9.1

[1] Moderate and marked expressions of osteoarthritis are reported.
[2] See Table 1 for references.

the Mariana Islands is 5.8%. Similar frequencies of premortem tooth loss are observed in Apurguan (5.8%), Rota (4.7%), and Oleai (6.1%). No statistically significant differences are noted when a combined total incidence of premortem tooth loss for Guam (5.3%) is compared to Rota ($\chi^2 = 0.153$, $P > .05$), or when Apurguan (5.8%) is compared with the remaining skeletal series from Guam (4.3%) ($\chi^2 = 2.965$, $P > .05$), Rota ($\chi^2 = 0.449$, $P > .05$), or Saipan ($\chi^2 = 3.313$, $P > .05$). Slightly higher frequencies of premortem tooth loss are observed in the Oleai sample (6.1%) and in the other skeletal series from Saipan. Significantly higher frequencies of premortem tooth loss were recorded in the Saipan series compared to Guam ($\chi^2 = 7.103$, $P \leq .01$), perhaps reflecting poorer dental health or an older age-at-death in the skeletal series from Saipan.

A significantly higher frequency of premortem tooth loss has been recorded in prehistoric Hawaiians (9.6%) when compared with the Mariana Islands ($\chi^2 = 57.807$, $P \leq .01$).

TABLE 14. Frequency of occurrence of advanced[1] appendicular osteoarthritis in the Mariana skeletal series[2] (totals per island—sexes combined)

Articular surface	Apurguan		Other Guam samples		Guam total		Rota total		Saipan total		Marianas total	
	A/O	%	A/O	%	A/O	%	A/O	%	A/O	%	A/O	%
Sterno-clavicular	1/23	4.3	0/7	0.0	1/30	3.3	0/1	0.0	0/2	0.0	1/33	3.0
Acromio-clavicular	1/8	12.5	0/6	0.0	1/14	7.1	0/1	0.0	1/4	25.0	2/19	10.5
Glenoid fossa	3/41	7.3	2/17	11.8	5/58	8.6	0/2	0.0	4/16	25.0	9/76	11.8
Humeral head	0/21	0.0	0/1	0.0	0/22	0.0	—	—	2/5	40.0	2/27	7.4
Radial head	2/49	4.1	1/20	5.0	3/69	4.3	0/2	0.0	0/8	0.0	3/79	3.8
Proximal ulna	3/65	3.1	3/26	11.5	6/91	6.6	0/2	0.0	1/8	12.5	7/101	8.9
Sacro-iliac	3/18	16.7	0/6	0.0	3/24	12.5	—	—	0/8	0.0	3/32	9.4
Acetabulum	0/29	0.0	0/17	0.0	0/46	0.0	0/2	0.0	5/17	29.4	5/65	7.7
Femoral head	0/17	0.0	0/13	0.0	0/30	0.0	0/2	0.0	0/5	0.0	0/35	0.0
Femoral condyle	4/30	13.3	1/9	11.1	5/39	12.8	—	—	2/6	33.3	7/45	15.6
Proximal tibia	1/26	3.9	1/6	16.7	2/32	6.3	—	—	3/4	75.0	5/36	13.9
Calcaneus	4/73	5.5	5/31	16.1	9/104	8.7	0/2	0.0	1/11	9.1	10/117	8.5
Talus	10/85	11.8	6/38	15.8	16/123	13.0	0/2	0.0	3/9	33.3	19/134	14.2
Temporo-mandibular	3/58	5.2	3/11	27.3	6/69	8.7	0/2	0.0	—	—	6/71	8.5
Total	35/543	6.4	22/208	10.6	57/751	7.6	0/16	0.0	22/103	21.4	79/870	9.1

[1] Moderate and marked expressions of osteoarthritis are reported.
[2] See Table 1 for references.

TABLE 15. *Frequency of occurrence of advanced[1] vertebral osteoarthritis and osteophytosis*

Skeletal samples[2]	Apurguan		Leo Palace		Academy Gym		SNM Hotel		Hafa Dai		Oleai		Total	
	A/O	%	A/O	%	A/O	%	A/O	%	A/O	%	A/O	%	A/O	%
Osteoarthritis of art. sur.														
Cervical	9/768	1.2	0/158	0.0	0/19	0.0	—	—	14/226	6.2	8/132	6.1	31/1303	2.4
Thoracic	45/970	4.6	1/142	0.7	0/8	0.0	0/26	0.0	25/355	7.0	48/242	19.8	119/1743	6.8
Lumbar	48/511	9.4	3/66	4.5	6/24	25.0	0/8	0.0	13/146	8.9	39/123	31.7	109/878	12.4
Total	102/2249	4.5	4/366	1.1	6/51	11.8	0/34	0.0	52/727	7.2	95/497	19.1	259/3924	6.6
Osteophytosis of centra														
Cervical	2/240	0.8	0/33	0.0	0/3	0.0	—	—	44/81	54.3	6/48	12.5	52/405	12.8
Thoracic	2/289	0.7	0/38	0.0	0/6	0.0	0/10	0.0	28/90	31.1	29/76	38.2	59/509	11.6
Lumbar	2/105	1.9	0/18	0.0	0/8	0.0	0/4	0.0	17/30	56.7	9/34	26.5	28/199	14.1
Total	6/634	0.9	0/89	0.0	0/17	0.0	0/14	0.0	89/201	44.3	44/158	27.8	139/1113	12.5

[1] Moderate and marked expressions are reported.
[2] See Table 1 for references.

The overall frequency of occurrence of caries in the remains from the Marianas is 9.9%. The overall frequency of occurrence of caries in the samples from Guam is 10.1%. The Apurguan series has one of the lowest recorded frequencies (2.6%) of caries in the skeletal series compared, a frequency which is statistically significant when compared to the rest of Guam ($\chi^2 = 49.148$, $P \leq .01$). Although no caries were recorded in the Academy Gym remains from Guam, this may be attributable to small sample size and the groups age-at-death. Generally, higher levels of carious lesions are observed in the skeletal series from Saipan (11.8%), a frequency which is not significantly different from that reported for the Guam total ($\chi^2 = 0.857$, $P > .05$). The frequency (3.5%) of caries in the Rota series is statistically lower than those recorded in Guam ($\chi^2 = 7.757$, $P \leq .01$) and Saipan ($\chi^2 = 9.917$, $P \leq .01$). Overall, the relatively low frequency of caries in the Marianas skeletal series is likely a result of the habit of betel-nut chewing. A statistically higher (14.0%) frequency of caries is reported in prehistoric Hawaiians, non-betel chewers ($\chi^2 = 19.631$, $P \leq .01$).

The frequency of occurrence of dental abscessing in the Mariana series (5.1%) generally follows the observed patterns for premortem tooth loss and caries. Slightly lower frequencies of dental abscessing are recorded in the series from Guam (4.6%) and Rota (4.7%) and higher frequencies are recorded in the series from Saipan (7.2%). The only significant differences in dental abscessing are recorded between the totals for Guam

TABLE 16. *Frequency of occurrence of advanced[1] vertebral osteoarthritis and osteophytosis (totals per island)*

Skeletal samples[2]	Apurguan		Other Guam samples		Guam total		Rota total		Saipan total		Marianas total	
	A/O	%	A/O	%	A/O	%	A/O	%	A/O	%	A/O	%
Osteoarthritis of art. sur.												
Cervical	9/768	1.2	0/178	0.0	9/946	1.0	—	—	22/358	6.1	31/1304	2.4
Thoracic	45/970	4.6	1/150	0.7	46/1120	4.1	0/26	0.0	73/597	12.2	119/1743	6.8
Lumbar	48/511	9.4	9/90	10.0	57/601	9.5	0/8	0.0	52/269	19.3	109/878	12.4
Total	102/2249	4.5	10/418	2.4	112/2667	4.2	0/34	0.0	147/1224	12.0	259/3925	6.6
Osteophytosis of centra												
Cervical	2/240	0.8	0/36	0.0	2/276	0.7	—	—	50/129	38.8	52/405	12.8
Thoracic	2/289	0.7	0/44	0.0	2/333	0.6	0/10	0.0	57/166	34.3	59/509	11.6
Lumbar	2/105	1.9	0/26	0.0	2/131	1.5	0/4	0.0	26/64	40.6	28/199	14.1
Total	6/634	0.9	0/106	0.0	6/740	0.8	0/14	0.0	133/359	37.0	139/1113	12.5

[1] Moderate and marked expressions are reported.
[2] See Table 1 for references.

TABLE 17. Comparison of oral-dental pathology in the permanent teeth from the Marianas

Skeletal series[1]	Premortem tooth loss		Caries		Abscessing	
	A/O	%	A/O	%	A/O	%
Matapang, Guam	7/119	5.9	5/66	7.6	5/61	8.2
Fujita, Guam	5/239	2.1	30/210	14.3	4/75	5.3
Right-of-Way, Guam	7/138	5.1	13/106	12.3	3/85	3.5
Apurguan, Guam	115/1996	5.8	39/149	2.6	59/1278	4.6
Leo Palace, Guam	23/427	5.4	11/378	2.9	10/199	5.0
Academy Gym, Guam	0/62	0.0	0/59	0.0	0/47	0.0
Guam total	157/2981	5.3	98/968	10.1	81/1745	4.6
Songsong, Rota	10/195	5.1	3/162	1.9	9/172	5.2
SNM Hotel, Rota	0/20	0.0	3/10	30.0	0/18	0.0
Rota total	10/215	4.7	6/172	3.5	9/190	4.7
San Antonio, Saipan	40/514	7.8	6/54	11.1	7/61	11.5
Hafa Dai, Saipan	32/320	10.0	9/28	32.1	2/28	7.1
Tanapag, Saipan	0/75	0.0	1/8	12.5	1/11	9.1
Oleai, Saipan	26/427	6.1	37/361	10.2	22/345	6.4
Saipan total	98/1336	7.3	53/451	11.8	32/445	7.2
Total	265/4532	5.8	157/1591	9.9	122/2380	5.1

[1] See Table 1 for references.

and Saipan ($\chi^2 = 4.709$, $P \leq .05$). Very similar frequencies of dental abscessing are observed in the Marianas (5.1%) and prehistoric Hawaiian series (5.2%), a difference which is not statistically significant ($\chi^2 = 0.011$, $P > .05$).

Two indicators of periodontal disease, calculus and alveolar resorption, are tabulated for the Mariana skeletal series (Table 18). There is considerable variation in the levels of advanced calculus build-up in these series. The highest levels of calculus are observed in the teeth from Songsong Village (32.4%) and Hafa Dai, Saipan (34.6%). Lower levels of calculus are observed in the series from Guam. In Apurguan, the frequency of advanced calculus build-up is 19.7%. A significant difference ($\chi^2 = 38.023$, $P \leq .01$) was found when the frequencies for Apurguan and all other series were compared. The overall frequency of occurrence of advanced calculus build-up in the Mariana series is 15.3%. A significantly lower frequency (6.5%) was observed in prehistoric Hawaiians ($\chi^2 = 193.622$, $P \leq .01$).

The accumulation of calculus has been shown to be positively associated with betelnut chewing as a result of the use of lime (Hanson, 1988). The frequency of betelchewers is quite high in the Apurguan dental series so the lower rates of calculus in this series may be the result of loss of the deposit because of bone disturbance, movement, etc.

Advanced levels of resorption of the alveolus, or the amount of tooth root that is exposed above the alveolar bone margin, in the larger skeletal series range from 25.2% to 56.3%. The skeletal series from Rota and Saipan have nearly twice the frequency of occurrence of alveolar resorption as the Guam series, (χ^2, $P \leq .01$). The overall frequency of occurrence of advanced alveolar resorption in the Mariana Islands is 37.7%. Slightly higher frequencies of advanced alveolar resorption are observed in prehistoric Hawaiians (49.0%), a difference which is statistically significant ($\chi^2 = 70.463$, $P \leq .01$).

Finally, the incidence of severe dental attrition, tooth wear that exposes the dentin, pulp and root, is highest in the Saipan island series (51.9%), a statistically significant ($P \leq .01$) difference from the Guam (26.3%) and Rota (27.3%) island totals. The overall frequency of advanced attrition in the Mariana remains is 30.3%. A significantly higher frequency of occurrence (44.3%) of advanced attrition has been recorded in prehistoric Hawaiians ($\chi^2 = 174.257$, $P \leq .01$) (Pietrusewsky and Douglas, 1994).

In summary, while the dental health of Mariana Islanders is relatively good, there are indications of interisland differences.

TABLE 18. Periodontal disease and attrition in permanent teeth of Pacific samples

Skeletal series[1]	Calculus[2]		Alveolar resorption[3]		Attrition[4]	
	A/O	%	A/O	%	A/O	%
Matapang, Guam	6/69	8.7	27/61	44.3	47/69	68.1
Fujita, Guam	8/209	3.8	21/57	36.8	38/205	18.5
Right-of-Way, Guam	19/100	19.0	37/77	48.1	72/104	69.2
Apurguan, Guam	253/1284	19.7	210/809	26.0	328/1457	22.5
Leo Palace, Guam	23/308	7.5	30/119	25.2	90/370	24.3
Academy Gym, Guam	6/54	11.1	0/25	0.0	21/60	35.0
Guam total	315/2024	15.6	325/1148	28.3	596/2265	26.3
Songsong, Rota	44/136	32.4	80/142	56.3	47/161	29.2
SNM Hotel, Rota	0/10	0.0	0/4	0.0	0/11	0.0
Rota total	44/146	30.1	80/146	54.8	47/172	27.3
San Antonio, Saipan	4/48	8.3	57/86	66.3	37/59	62.7
Hafa Dai, Saipan	9/26	34.6	22/28	78.6	10/26	38.5
Tanapag, Saipan	0/8	0.0	2/11	18.2	6/8	75.0
Oleai, Saipan	28/365	7.7	143/248	57.7	175/346	50.6
Saipan total	41/447	9.1	224/373	60.0	228/439	51.9
Total	400/2617	15.3	629/1667	37.7	871/2876	30.3

[1] See Table 1 for references.
[2] Includes calculus deposits scored as moderate and marked only.
[3] Includes expressions of alveolar resorption scored as moderate and marked only.
[4] Includes wear scored as reaching the dentin (moderate), pulp and root only.

Saipan Island frequencies of premortem tooth loss, caries, abscessing, and attrition are all greater than Guam and Rota Island totals. While these differences may be attributable to small sample size and older age-at-death, there may also be environmental considerations. Comparison of Mariana dental pathology frequencies with those of precontact Hawaiians reflects the relative contribution of betel-nut chewing to the preservation of dental health.

Infectious diseases

It is widely accepted that venereal syphilis was absent in the Mariana Islands prior to contact with Europeans (Baker and Armelagos, 1988; Stewart and Spoehr, 1952). Hence, bony lesions with manifestations typical of treponemal infections from this region of the Pacific are usually diagnosed as evidence of yaws (see e.g., Rothschild and Heathcote, 1993). One of the first published accounts of yaws in skeletal remains from the Marianas is that of Stewart and Spoehr (1952), who describe multiple lesions in the cranium and limb bone shafts of a 13–14-year-old from a Latte Period site (Blue Site) on Tinian (dated AD 854 ± 145). Since then Hanson (1988) has reported on possible evidence of treponemal infection (periostitis) in six individuals from Rota. No signs of treponemal disease are described in the nine individuals recovered from the Duty Free Site, Saipan, also examined by Hanson (1989). More recently, Stodder et al. (1992) have described treponemal infection in the large skeletal series from the Hyatt Hotel on Guam, and Rothschild and Heathcote (1993) have published on treponemal yaws in the skeletal remains from the Gognga-Gun Beach site on Guam.

In the present study, bony changes attributed to treponemal infection (e.g., periosteal reaction, gummatous osteitis and cloacae) have been observed in the skeletal remains from Guam, Rota, Tinian, and Saipan (Table 19). The total number of individuals affected is 33. Lesions have been found in individuals as young as 6 years of age to old aged individuals. Young, middle-aged, and old adult individuals are about equally affected. Of the affected adults whose sex could be determined, nine are male and 11 are female. Only one child and two adolescent skeletons are reported as exhibiting lesions consistent with treponemal infection but subadults (N = 87) are typically underrepresented in these skeletal samples. For adults, the frequency of occurrence of treponemal infection is 30/286, or 10.5%. Using the total

TABLE 19. Treponemal infection in the Mariana Islands skeletal series

Skeletal series[1]	N	Minimum number of individuals with bony changes suggestive of treponemal infection: Adults M	F	?	Total	Subadults	Total affected	Individuals and bones affected
Guam								
Apurguan[2]	147	8	3	1	12/101 (11.9%)	1/46 (2.2%)	13/147 (8.8%)	Burial 10, a 6–8-year-old: right ulnar diaphysis Burial 14A, a 25–30-year-old male: right tibia Burial 40A, a 40–45-year-old female: both tibiae and fibulae Burial 51, an ?adult male: left tibia Burial 54, a 45–50-year-old male: right femur, tibia, and fibula; left tibia Burial 61, a 19–25-year-old male: right tibia Burial 73, a 35–40-year-old female: right and left tibia Burial 85A, a 25–30-year-old male: left femur Burial 88, an 18–23-year-old female: left rib Burial 101, a 30–40-year-old male: right radius Burial 108, a 45–50-year-old male: right tibia Burial 114, a young adult male: proximal and middle phalanges of right third finger
Fujita	28	0	0	0	0/24 (0.0%)	0/4 (0.0%)	0/28 (0.0%)	None
Right-of-Way	16	0	1	0	1/10 (10.0%)	0/6 (0.0%)	1/16 (6.3%)	Burial 8, an old adult female: right radius
Matapang	20	0	0	0	0/18 (0.0%)	0/2 (0.0%)	0/20 (0.0%)	None
Leo Palace[3]	26	0	1	0	1/16 (6.3%)	0/10 (0.0%)	1/26 (3.8%)	Burial 19, a young adult female: left distal tibia
Academy Gym	4	0	0	0	0/3 (0.0%)	0/1 (0.0%)	0/4 (0.0%)	None
Guam total	241	8	5	1	14/172 (8.1%)	1/69 (1.4%)	15/241 (6.2%)	
Rota								
Songsong Village	12	0	3	0	3/10 (30.0%)	1/2 (50.0%)	4/12 (33.3%)	Burial 41-1, a middle-aged female: frontal bone; left tibia, ulna, and radius Burial 42-1, a young adult female: right and left tibiae Burial 42-S, a 14–18 year old female: right and left tibiae; right(?) ulna shaft fragment which may belong to Burial 42-S Burial 44-1, an old adult female: nasal, palatal, and frontal regions; the long limb bones of the arms and legs
SNM Hotel	2	0	0	0	0/1 (0.0%)	0/1 (0.0%)	0/2 (0.0%)	None
Rota total	14	0	3	0	3/11 (27.3%)	1/3 (33.3%)	4/14 (28.6%)	
Tinian								
Latte House	6	0	1	0	1/3 (33.3%)	0/3 (0.0%)	1/6 (16.7%)	Burial 1, a 35–40-year-old female: frontal bone and all long limb bones
Unai Chulu	14	0	0	1	1/14 (7.1%)	—	1/14 (7.1%)	An adult of unknown sex: one femur fragment
Tinian total	20	0	1	1	2/17 (11.8%)	0/3 (0.0%)	2/20 (10.0%)	
Saipan								
Marianas High	5	0	0	0	0/3 (0.0%)	0/2 (0.0%)	0/5 (0.0%)	None
Grotto Site	2	0	0	0	0/2 (0.0%)	—	0/2 (0.0%)	None
San Antonio	33	0	0	0	0/32 (0.0%)	0/1 (0.0%)	0/33 (0.0%)	None

(continued)

TABLE 19. Treponemal infection in the Mariana Islands skeletal series

Skeletal series[1]	N	Minimum number of individuals with bony changes suggestive of treponemal infection: Adults M	F	?	Total	Subadults	Total affected	Individuals and bones affected
Hafa Dai Beach[4]	23			7	7/19 (36.8%)	0/4 (0.0%)	7/23 (30.4%)	<u>Adults and subadults</u> Cranium: 1/20 or 5.0% crania affected Clavicle: 1/25 or 4.0% sides affected Humerus: 2/29 or 6.9% sides affected Ulna: 13/27 or 48.1% sides affected Femur: 6/20 or 30.0% sides affected Tibia: 4/23 or 17.4% sides affected Fibula: 1/21 or 4.8% sides affected
Oleai	35	1	2	1	4/30 (13.3%)	1/5 (20.0%)	5/35 (14.3%)	Burial 2, a 18–20-year-old of unknown sex: both fibulae Burial 3, a middle-aged female: right tibia and fibula Burial 11, a 45–50-year-old female: both tibiae and fibulae Burial 13, a 45–55-year-old male: frontal bone and both zygomatic bones Burial 20, a 12–15-year-old of unknown sex: left tibia and fibula
Saipan Total	98	1	2	8	11/86 (12.8%)	1/12 (8.3%)	12/98 (12.2%)	
Mariana Total	373	9	11	10	30/286 (10.5%)	3/87 (3.4%)	33/373 (8.8%)	

[1] See Table 1 for references.
[2] N excludes five sets of fetal remains. MNI of affected individuals excludes an adult ?sex third metatarsal intrusive to Burial 107.
[3] N excludes one set of fetal remains. MNI of affected individuals excludes several Trench A misc. shaft fragments which have evidence of infection.
[4] MNI for affected individuals of unknown sex and Total MNI are based on seven right ulnae. Affected bone frequencies were calculated for the present study using the original data.

MNI of 373 for these series, the prevalence of treponemal infection in adults and subadults, by individual, is 8.8%.

For several skeletal series, Fujita (Guam), Matapang (Guam), and San Antonio (Saipan), no evidence of treponemal infection was observed. Using the data in Table 19, the highest frequencies of occurrence of treponemal infection are noted in the skeletal series from Songsong, Rota (33.3%); Hafa Dai, Saipan (30.4%); Latte House, Tinian (16.7%); Oleai, Saipan (14.3%); Apurguan, Guam (8.8%); and Unai Chulu, Tinian (7.1%). Examining the totals for each of the four main islands, the highest frequency of occurrence occurs in Rota (28.6%), followed by Saipan (12.2%), Tinian (10.0%), and Guam (6.2%).

Given the shortcomings of reporting prevalence of paleopathological conditions in skeletal remains by individual, the frequency of occurrence of treponemal infection by bone element in adults for these same skeletal series is given in Table 20. As would be expected by the typical skeletal pattern of treponemal infection, the two most frequently affected bones are the tibia (15.2%) and ulna (11.3%). The highest frequency of occurrence of affected tibiae occurs in the skeletal series from Oleai on Saipan (57.1%) followed by the sample from Songsong Village on Rota (50.0%). For the ulna, the highest frequency of occurrence is the one reported for the Hafa Dai series from Saipan (48.1%) followed by Songsong Village (25.0%) from Rota. For Apurguan, one of the largest and most recently studied skeletal series from Guam, only the tibia (17.9%) and femur (3.2%) are affected. The Hafa Dai sample is unusual in that the most frequently affected bone is the ulna (48.1%), followed by the femur (30.0%) and then the tibia (17.4%). This pattern is different from most of the other skeletal series investigated.

Frequencies of infection based on bone element are similar to those generated by individuals. Again, Songsong Village (22.0%), Hafa Dai (16.0%), and Oleai (13.6%) skeletal

TABLE 20. Treponemal infection in Mariana Island skeletal series in adult bones (by bone element)

Burial site	Adult skeletal element								
	Cranium	Clavicle	Humerus	Radius	Ulna	Femur	Tibia	Fibula	Total
Guam									
Apurguan									
A/O	0/21	0/75	0/76	0/78	0/31	2/62	10/56	0/56	12/455
(%)						(3.2%)	(17.9%)		(2.6%)
Fujita									
A/O	0/2		0/4			0/10	0/8		0/24
(%)									(0.0%)
ROW-A									
A/O	0/2	0/2	0/6	1/2	0/2	0/9	0/3		1/26
(%)				(50.0%)					(3.8%)
Matapang									
A/O			0/4	0/3	0/2	0/9	0/12	0/2	0/32
(%)									(0.0%)
Leo Palace									
A/O	0/2	0/13	0/10	0/12	0/11	0/9	1/11	0/12	1/80
(%)							(9.1%)		(1.3%)
Academy Gym[1]									
A/O	0/1	0/4	0/4	0/2	0/2	0/2		0/1	0/16
(%)									(0.0%)
Guam total									
A/O	0/28	0/94	0/104	1/97	0/48	2/101	11/90	0/71	14/633
(%)				(1.0%)		(2.0%)	(12.2%)		(2.2%)
Rota									
Songsong									
A/O	2/6	0/11	2/11	3/12	3/12	2/13	5/10	1/7	18/82
(%)	(33.3%)		(18.2%)	(25.0%)	(25.0%)	(15.4%)	(50.0%)	(14.3%)	(22.0%)
SNM Hotel[1]									
A/O		0/2	0/2	0/2	0/2				0/8
(%)									(0.0%)
Rota total									
A/O	2/6	0/13	2/13	3/14	3/14	2/13	5/10	1/7	18/90
(%)	(33.3%)		(15.4%)	(21.4%)	(21.4%)	(15.4%)	(50.0%)	(14.3%)	(20.0%)
Tinian									
Latte House[1]									
A/O	1/2	0/3	0/6	0/3	0/3	0/4	0/4	0/2	1/27
(%)	(50.0%)								(3.7%)
Unai Chulu[3]									
A/O		0/5	0/23	0/20	0/24	1/17	0/9	0/11	1/109
(%)						(5.9%)			(0.9%)
Tinian total									
A/O	1/2	0/8	0/29	0/23	0/27	1/21	0/13	0/13	2/136
(%)	(50.0%)					(4.8%)			(1.5%)
Saipan									
Marianas HS[1]									
A/O	0/1	0/1	0/2			0/1			0/5
(%)									(0.0%)
Grotto[1]									
A/O	0/1	0/3	0/2	0/1	0/2	0/2			0/11
(%)									(0.0%)
San Antonio[2]									
A/O	0/14	0/18	0/22	0/7	0/15	0/12	0/15	0/1	0/104
(%)									(0.0%)
Hafa Dai[3]									
A/O	1/19	1/22	2/27	0/16	13/27	6/20	4/23	1/21	28/175
(%)	(5.3%)	(4.5%)	(7.4%)		(48.1%)	(30.0%)	(17.4%)	(4.8%)	(16.0%)
Oleai									
A/O	1/11	0/15	0/10	0/9	0/9	0/11	4/7	6/9	11/81
(%)	(9.1%)						(57.1%)	(66.7%)	(13.6%)
Saipan total									
A/O	2/46	1/59	2/63	0/33	13/53	6/46	8/45	7/31	39/376
(%)	(4.3%)	(1.7%)	(3.2%)		(24.5%)	(13.0%)	(17.8%)	(22.6%)	(10.4%)
Mariana total									
A/O	5/82	1/174	4/209	4/167	16/142	11/181	24/158	8/122	73/1235
(%)	(6.1%)	(0.6%)	(1.9%)	(2.4%)	(11.3%)	(6.1%)	(15.2%)	(6.6%)	(5.9%)

Bone frequency determined from reported measurements using maximum frontal breadth in the cranium and the midshaft measurements of the long bones.
Miscellaneous bones are not included in these figures.
[1] Count made from the burial descriptions.
[2] Fibulae were not described except in the single articulated burial.
[3] Pathology recorded per bone observed.

series exhibit the highest frequencies of treponemal infection. In the island totals, the islands of Rota (20.0%) and Saipan (10.4%) have the highest frequencies of treponemal bone infection while Guam (2.2%) and Tinian (1.5%) have the lowest.

Rothschild and Heathcote (1993) report a frequency of occurrence (calculated by individual) of treponemal infection of 19% for Gognga-Gun Beach and Stodder et al. (1992) report an individual frequency of 20% (37/183) at the Hyatt Hotel site, both located in Tumon Bay on Guam. Although higher frequencies are reported for several other smaller skeletal series in the present study, the frequency of occurrence for Apurguan (8.8%) is considerably lower. Unfortunately, these authors do not report the frequency of occurrence of treponemal infection by bone element making comparisons problematic. Differences in the criteria used to recognize treponemal infection in these remains, and the method of calculating prevalence, may account for this discrepancy. Alternatively, this apparent difference in the frequency of occurrence of treponemal infection between two neighboring sites, at Agana Bay and Tumon Bay on Guam, is intriguing and explanations may be sought among possible temporal, environmental, nutritional, and/or social status differences between these skeletal series.

DISCUSSION AND CONCLUSIONS

The present survey of a number of skeletal and dental indicators recorded in several different Chamorro skeletal series representing Guam, Rota, Tinian, and Saipan provides a preliminary assessment of health and disease in the Mariana Islands prior to contact with Europeans in 1521. Inclusion of skeletal samples from several different sites and islands within the northern Marianas chain allows intersite and interisland comparisons.

Many of the skeletal series surveyed are small and are characterized by uneven age and sex distributions, making demographic comparisons difficult. Subadults are underrepresented in several of the series and adult males often outnumber adult females. The largest skeletal series, Apurguan, more closely approximates a normal cemetery population. Several demographic estimators calculated for the larger series (e.g., Leo Palace, Oleai, and Apurguan) indicate values generally lower than other archaeological samples, reflecting underrepresentation of subadults. Overall, however, these estimators suggest a healthy fertility rate. Life expectancy at birth ranges from 26.39 years to 33.71 years. Relatively high mortality occurs in the young child age intervals. The average adult age ranges from 39.4 to 43.5 years. Traditional Chamorro mortuary practices and other factors may partly explain this demographic picture.

The mean stature for prehistoric Chamorro males is 173.1 cm and for Chamorro females it is 161.3 cm. These stature estimates indicate that the prehistoric Chamorros were relatively tall, especially when compared to living Chamorros from Saipan who, on average, were 10 cm shorter. Furthermore, the average stature of the Chamorros is similar to that of Polynesians in precontact Hawaiʻi. Because of the strong correlation between stature and environmental factors, the results presented here suggest that prehistoric Chamorro had more than adequate nutrition and growth retardation in Chamorro children was not a problem. Because the small sample sizes, it is premature to comment on any interisland differences in stature among the prehistoric Chamorro. Stature estimates that are available indicate that there is little fluctuation in stature between sites or between different islands. Until population-specific formulae for estimating stature become available for the Marianas, researchers have little choice but to use those developed for New Zealand Maori or to use the formulae where ethnicity is not a consideration.

The relatively high (32.5%) prevalence of enamel hypoplasia observed in the permanent incisors and canines among the Chamorros suggests that they experienced relatively high levels of physiological stress. A significant difference in dental enamel hypoplasia between males and females was noted for several of the series which suggests sex-related differences in childhood health. For one of the largest skeletal series surveyed, Apurguan, this indicator of physiological stress is higher in males than in females.

When frequencies for all groups are combined, however, the prevalence of this indicator is nearly the same in both sexes. As expected, the skeletal series from Saipan and Rota have some of the highest frequencies of occurrence of enamel hypoplasia, suggesting that environmental differences, such as the mineral content of water, adequacy of food, and susceptibility to typhoons and their aftereffects, may have had a differential or adverse impact on the inhabitants of these islands. Compared to prehistoric Hawaiians, who had a much lower frequency of occurrence (7.7%) of enamel hypoplasia, the health of the Mariana Islanders appears to have been compromised by nutritional deficiencies and infectious diseases.

Cribra orbitalia in adult Mariana Islanders is restricted to males, where the frequency of occurrence is 20.3%. The frequency (5.9%) is very much lower in Apurguan, the largest skeletal series surveyed, suggesting iron deficiency anemia was not a problem in this prehistoric Chamorro series. However, as was reported for enamel hypoplasia, the highest frequencies of occurrence of cribra orbitalia are those observed in the skeletal series from Saipan and Rota, which may indicate that populations on these islands may have been subjected to parasitic diseases, iron-deficient diets, and/or other chronic stressors in their environment than those who lived on Guam. By contrast, in prehistoric Hawaiians the prevalence (13.5%) of cribra orbitalia is lower and virtually identical in adult males and females. Although the overall frequency is higher in prehistoric Mariana Islanders, no statistical significance was observed in the overall prevalence of this indicator when Chamorros and Hawaiians are compared.

The frequency of healed limb bone fractures is surprisingly low (0.6%) in the prehistoric Chamorro, suggesting that there was little deliberate or accidental injury during prehistoric times. This latter finding would seem to corroborate the view that large scale organized warfare did not exist in prehistoric times (Hunter-Anderson and Butler, 1995), although the weapons used by the Chamorro may not have left recognizable wounds in the skeletal record. No long limb bone fractures were observed in the skeletal samples from Rota, Tinian, or Saipan. Although still low compared to prehistoric (Steinbock, 1976) and modern (Garraway et al., 1979) populations, a significantly higher prevalence of healed bone fractures is observed in prehistoric Hawaiians when compared to the Chamorro. The frequency of spondylolysis, interpreted by many as a stress fracture of the lumbar vertebrae, however, is significantly higher in Chamorros from Guam than in prehistoric Hawaiians, indicating more stress in the lower spine. No examples of spondylolysis, however, are observed in the lumbar vertebrae from Rota, Saipan, or Tinian, which raises the possibility that there are differences in occupation or physical activity, especially ones that place a heavy mechanical demand on the lower back, between the inhabitants of these islands and those living on Guam. Others (e.g., Arriaza, 1995) have suggested a link between this stress fracture and latte structure construction in the Mariana Islands.

Levels of advanced osteoarthritis of the limb skeleton in the Chamorro series largely reflect the age of the individuals in these series, the accumulative effects of physical activity over the lifetimes of these individuals, and/or a possible genetic predisposition to osteoarthritis. Although samples sizes are small, there is slightly more advanced osteoarthritis in the skeletal series from Oleai on Saipan than in the skeletal series from Guam. Compared to prehistoric Hawaiians, there is a higher prevalence of advanced osteoarthritis in Chamorros, suggesting that the physical demands in this Pacific Island society were greater. The most severely affected regions are the knee, ankle, and shoulder, a pattern which may signal differences in behavior. However, given the lack of definitive patterns relating the prevalence of degenerative pathology, subsistence, and behavior (Larsen, 1995), further comment seems inappropriate. Advanced vertebral osteoarthritis and osteophytosis in the Chamorro series is similar to frequencies reported for prehistoric Hawaiians. As was the case for osteoarthritis in the appendicular skeleton, the highest frequencies of vertebral osteoarthritis and osteophytosis are observed in the skeletal series from Saipan.

Despite the consumption of largely cariogenic diets, ones which are especially rich in root and tree starches, the dental health of prehistoric Marianas Islanders is relatively good. The frequency of caries, premortem tooth loss, dental abscessing, and dental attrition are all low in the Chamorro series. In contrast to these observations, advanced calculus, or tartar, buildup, one indicator of periodontal disease, is relatively high in the Chamorros. As elaborated elsewhere (see e.g., Hanson, 1989, this issue), the practice of chewing betel nut may be responsible for this observed pattern of dental pathology. The highest frequencies of caries, premortem tooth loss, abscessing, attrition, and alveolar resorption are observed in the skeletal series from Saipan. Again, these observed differences may reflect the older age profile of these samples and/or environmental and nutritional differences between Guam and the islands north of Guam.

Evidence of treponemal disease, most likely yaws, has been documented in the skeletal remains from Guam, Rota, Tinian and Saipan. Slightly higher frequencies of treponemal infections are found in the skeletal remains from Rota, Tinian, and Saipan than in those from Guam. The former islands were generally found to have greater prevalence of stress indicators overall, suggesting that infectious disease may be at least partly responsible. Reporting the frequency of occurrence of treponemal infections, and other paleopathological conditions, in incomplete and poorly preserved skeletal remains will continue to pose problems for future researchers, particularly those doing comparative work. Because of the incomplete nature of skeletal remains in general, and specifically those from the Marianas, it is imperative that the presence or absence of all skeletal elements be enumerated in reporting the prevalence of these conditions, a procedure which is gaining acceptance in paleopathology and paleoepidemiology (see e.g., Waldron, 1995; Buikstra and Ubelaker, 1994).

Although the data presented in this study suggest temporal differences, this question is best left for future research when more suitable samples become available. The majority of the skeletal samples investigated in this paper are from the Latte Period (AD 1000–1521). A few (e.g., San Antonio, Right of Way) probably fall toward the end of this period and may overlap with the early historic and historic periods. Only two samples in the present study, Matapang and Fujita, are pre-Latte in origin, which, because they are small samples, provide only a glimpse of possible temporal changes in the prehistoric Chamorro. In the Fujita series, there are elevated frequencies of enamel hypoplasia, cribra orbitalia, advanced osteoarthritis, dental caries, and dental attrition, suggestive of greater stress in one of the earliest dated skeletal series from the Marianas. With the exception of a higher frequency of dental attrition, none of the indicators in the Matapang sample stand out as unusual when compared to the other samples investigated.

This initial examination of indicators of health and disease in the Mariana Islands raises a number of intriguing questions regarding the possibility of interisland differences in environment and/or resource availability and the possible effects of microclimates and natural disasters on smaller islands. For several indicators of health, such as enamel hypoplasia, cribra orbitalia, advanced osteoarthritis, and treponemal infection, a pattern is beginning to emerge that suggests that the skeletal series from Saipan, Rota, and, to a lesser extent, Tinian experienced more stress than the prehistoric inhabitants of Guam. Given its small size and frequent water shortages, it was predicted that the highest frequencies of skeletal and dental stress should occur in the Rotese series. On the contrary, a generally higher prevalence of stress indicators was reported for the series from Saipan, the most northerly of the southern islands investigated. The possibility exists that when conditions (e.g., periods of extended droughts) on Rota got bad, the people left for larger islands such as Guam. Alternatively, the relatively low population density on Rota compared to Saipan may account for the lower prevalence of these disease/health indicators. The higher prevalence of spondylolysis and healed limb bone fractures in the skeletons from Guam further suggests that the earlier inhabitants of this island may have experienced more

stress involving physical labor and/or cultural practices than those living on the islands north of Guam. Although not one of the original research questions addressed in this paper, significant sex differences in the frequencies of occurrence for some of the indicators (e.g., cribra orbitalia and spondylolysis) were observed, results which are worthy of further investigation. Answers to these, and other, questions will become available when more accurate and detailed dating of the burials is available and when there is greater standardization of the methods used by different researchers.

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